RECONSTRUCTION OF RADAR RFLECTIVITY IN CLUTTER AREAS

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1. INTRODUCTION

The production of Radar Quantitative Precipitation Estimates (QPE) requires processing the observations to ensure their quality and its conversion into the variable of interest (e.g., precipitation rates). Some of the steps involve the reconstruction of the meteorological signal in areas where the signal is lost (e.g. due to total beam blockage or severe path attenuation by heavy rain) or strongly contaminated, for instance, in areas affected by ground or sea clutter.

In the latter case, the meteorological signal is often reconstructed through the analysis of the Doppler spectrum. Alternatively, for uncorrected moment data, the reconstruction is done first by identifying clutter-affected areas based on the analysis of statistical properties of radar measurements, and then the reconstruction of the meteorological signal is performed either by horizontal interpolation, by extrapolation of non-contaminated PPIs aloft or a combination of the two, as proposed by Sánchez-Diezma et al. (2001) by adapting the reconstruction to the type of precipitation affecting clutter-contaminated areas.

Here, an alternative reconstruction method is proposed here using the space and time structure of the field. The developed method has been implemented to reflectivity fields under different rainfall situations (scattered convection, organized convection, and widespread precipitation –see Section 2). For the evaluation of the method, several formulations of the reconstruction method (presented in Section 3) have been implemented and compared between radar estimates and raingauge observations (Section 4).

2. DATA USED

The dataset used in this study were collected with the Corbera de Llobregat C-band Doppler radar of the Spanish Agency of Meteorology. As part of the quality control of radar reflectivity data, the algorithm of Delrieu et al. (1995) has been implemented to mitigate the effect of beam blockage. The identification of non-meteorological echoes in reflectivity data has been performed with the methodology of Berenguer et al. (2006). It is based on a fuzzy-logic classifier that discriminates non-meteorological echoes (ground and sea clutter) from weather echoes using a number of statistics.

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3. FORMULATION OF THE METHOD

3.1 *General formulation*

Once clutter-contaminated areas have been identified in reflectivity data, the meteorological signal is reconstructed capitalizing on the spatial and temporal structure of the reflectivity field (e.g. see Zawadzki, 1973). The proposed approach follows the Ordinary Kriging formulation (see, e.g. Isaaks and Srivastava, 1989). Accordingly, The reconstructed radar field at location and time $\mathbf{x}=[x_o,y_o,z_o,t_o]$ is estimated as a linear combination of n observations $Z(\mathbf{x}_i)$:

$$\hat{Z}(\mathbf{x}) = \sum_{i=1}^{n} \lambda_i \, Z(\mathbf{x}_i) \tag{1}$$

The weights λ_i that make the estimate optimal and unbiased can be obtained by solving the following linear system:

$$\begin{bmatrix} \gamma_{11} & \cdots & \gamma_{1n} & 1 \\ \vdots & \ddots & \vdots & \vdots \\ \gamma_{n1} & \cdots & \gamma_{nn} & 1 \\ 1 & \cdots & 1 & 0 \end{bmatrix} \begin{bmatrix} \lambda_1 \\ \vdots \\ \lambda_n \\ \xi \end{bmatrix} = \begin{bmatrix} \gamma_1 \\ \vdots \\ \gamma_n \\ 1 \end{bmatrix} \tag{2}$$

where γ_{ij} is the semi-variogram for a separation vector $\mathbf{\Delta}_{ij}=\mathbf{x}_i-\mathbf{x}_j$, and γ_i is the one for a separation vector $\mathbf{\Delta}_i=\mathbf{x}_i-\mathbf{x}$. A Lagrange multiplier (ξ) is introduced to guarantee that the estimate $\hat{Z}(\mathbf{x})$ is unbiased. The semi-variogram is generally defined as:

$$\gamma(\Delta) = \frac{1}{2}\mathrm{Var}\left[Z(\mathbf{x}) - Z(\mathbf{x}+\Delta)\right] \approx \frac{1}{2}\frac{1}{N}\sum_{k=1}^{N}\left[Z(\mathbf{x}_k) - Z(\mathbf{x}_k+\Delta)\right]^2 \tag{3}$$

Where Var[ ] denotes the variance operator, Δ is the lag, and N is the number of points used to estimate the semi-variogram.

3.2 *Specific formulations*

The general methodology presented above has been implemented to reconstruct the clutter-contaminated areas (the gaps) using 4-Dimension neighboring reflectivity observations: (i) in the horizontal plane, (ii) in the closest non-contaminated PPI, and (iii) the closest radar volume scan in time (after compensating the effect of the motion).

To illustrate the contribution of each component to the final result, the following configurations have been tested:

HOR: Horizontal interpolation

The reflectivity estimate $\hat{Z}(\mathbf{x})$ at a given location $\mathbf{x}=[x_o,y_o,z_o,t_o]$ is obtained by interpolating the N_H neighboring noncontaminated observations on the same PPI and for the same time step. That is, in (1), $Z(\mathbf{x_i})=Z(x_i,y_i,z_o,t_o)$.

VERT: Vertical extrapolation

The reflectivity estimate $\hat{Z}(\mathbf{x})$ at a given location $\mathbf{x}=[x_o,y_o,z_o,t_o]$ is obtained by extrapolating the closest noncontaminated reflectivity observation in the vertical (typically above). Note that the reconstruction performed with this method does not apply the ordinary kriging approach, because the estimate is obtained by direct vertical extrapolation $\hat{Z}(x_0,y_0,z_0,t_0)=Z(x_0,y_0,z_i,t_0)$ where z_i represents the height of the closest noncontaminated PPI.

TIM: Temporal reconstruction

The reconstructed value is taken as the observation in the previous Quality-Controlled volume scan taking into account the effect of the motion. The estimate at a given a location is obtained by following its trajectory backwards in time with a semi-Lagrangian scheme: $\hat{Z}(x_0,y_0,z_0,t_0)=Z(x_0-u\cdot\Delta t,y_0-v\cdot\Delta t,z_0,t_0-\Delta t)$, where (u,v) stands for the motion field of Z, and Δt is the time between two consecutive scans. This procedure is very similar to what is done in many nowcasting algorithms to extrapolate reflectivity observations to the future. The tracking algorithm to estimate the motion field and the extrapolation technique used here are the same as those presented by Berenguer et al. (2011). Similarly as for the VERT method, this approach does not apply the ordinary krigring approach because the estimate is obtained by direct extrapolation of the previous reflectivity field.

HV: Volumetric reconstruction

This method combines the observations used in methods HOR and VERT. Consequently, the vector of observations used in the reconstruction of $\hat{Z}(x_0,y_0,z_0,t_0)$ is composed of N_H neighboring observations on the same PPI $Z(\mathbf{x_i})=Z(x_i,y_i,z_o,t_o)$ and one observation in the vertical extrapolated from the closest noncontaminated PPI: $Z(\mathbf{x_i})= Z(x_o,y_o,z_i,t_o)$

HT: Horizontal-temporal reconstruction

This method combines the observations used in methods HOR and TIM. That is, the vector of observations is composed of N_H neighboring observations on the same PPI $Z(\mathbf{x_i})=Z(x_i,y_i,z_o,t_o)$ and the reflectivity value from the previous scan extrapolated with the motion field, $Z(x_0-u\cdot\Delta t,y_0-v\cdot\Delta t,z_0,t_0-\Delta t)$.

4. RESULTS

The 5 configurations presented above have been implemented over the radar reflectivity volume scans corresponding to a variety of rainfall situations. Also, the performance of these methods has been compared with the technique developed by Sánchez-Diezma et al. (2001), hereafter referred to as SD2001. This method is based on a pre-classification of weather echoes: horizontal interpolation is preferred in widespread precipitation areas (which prevents the extrapolation of enhanced reflectivity measurements from the radar bright band), while vertical extrapolation is preferred for convective cells with some vertical development.

To test the different methodologies it is necessary to have measurements of reference to compare them against the reconstructed values, and assess the quality of the results. With this purpose the three-dimensional structure of ground clutter is rotated in order to locate the clutter mask in a clutter-free area (as proposed by Sánchez-Diezma et al. 2001). At this new location the reference value is known (because the original data are not contaminated by clutter), and can be compared with the reconstruction.

Figure 1 shows the mean clutter map in clear air conditions for the Barcelona radar, and the location of the areas where the reconstruction has been performed in the evaluation of the different techniques.

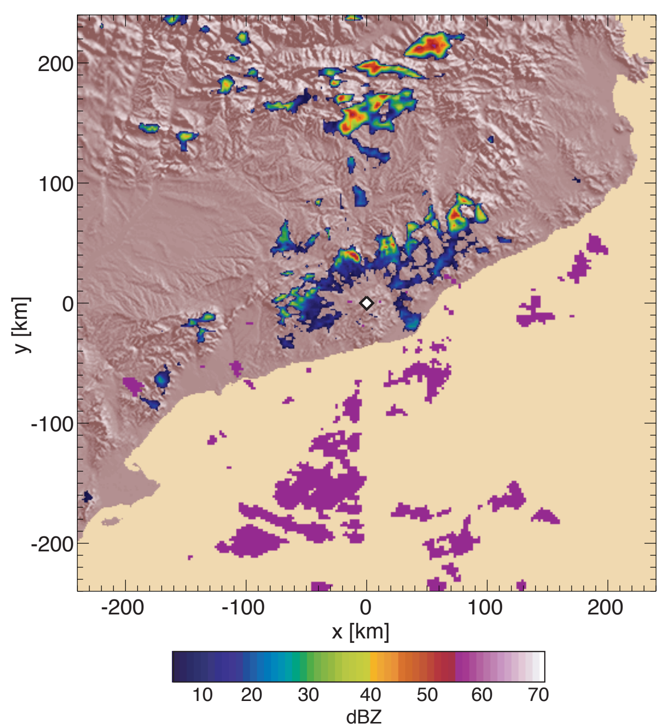

Fig. 1. Mean ground clutter map in clear air conditions for the Barcelona radar. The violet shaded areas show where the signal has been reconstructed for the evaluation of the different techniques. The diamond shows the radar location.

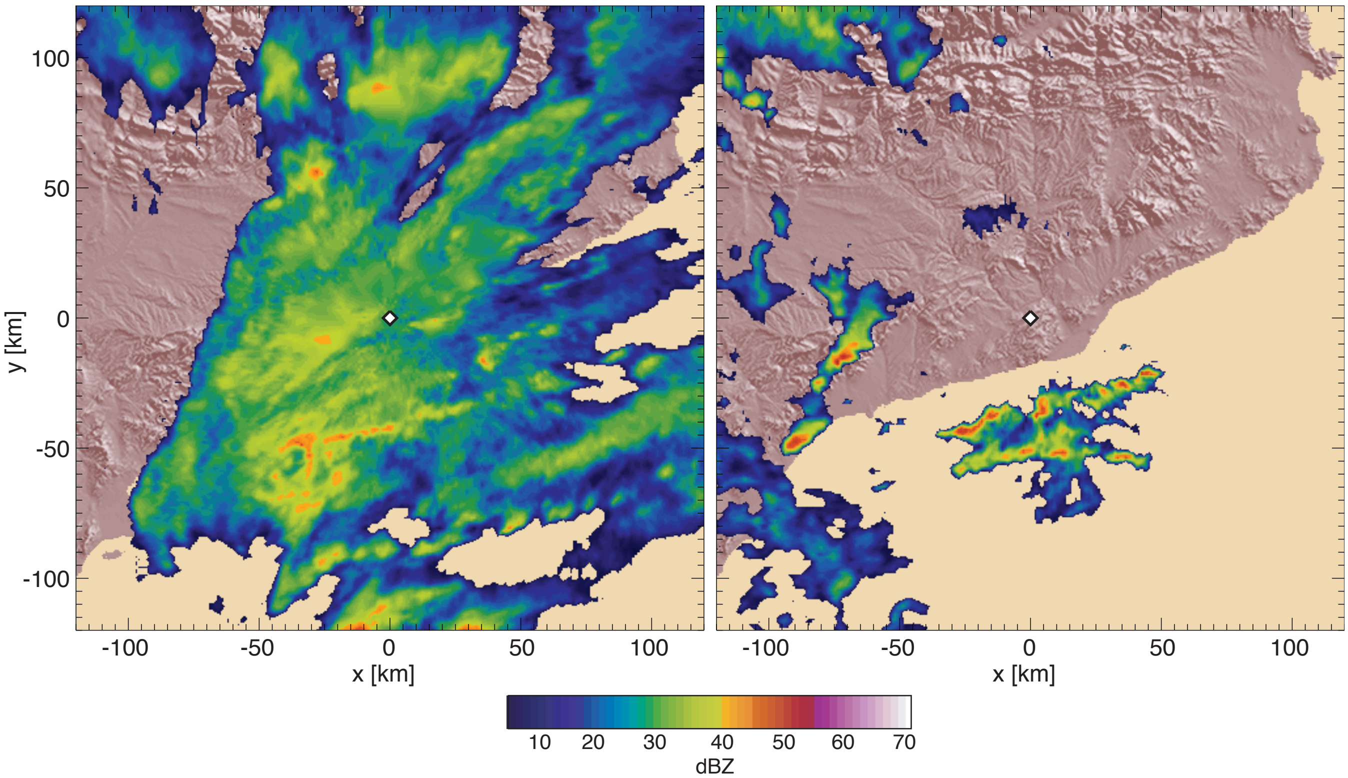

Fig. 2. Example reflectivity fields for the two analyzed events measured on July 19 2001 at 07:00 UTC (left), and on 08 October 2002 at 21:30 UTC (right).

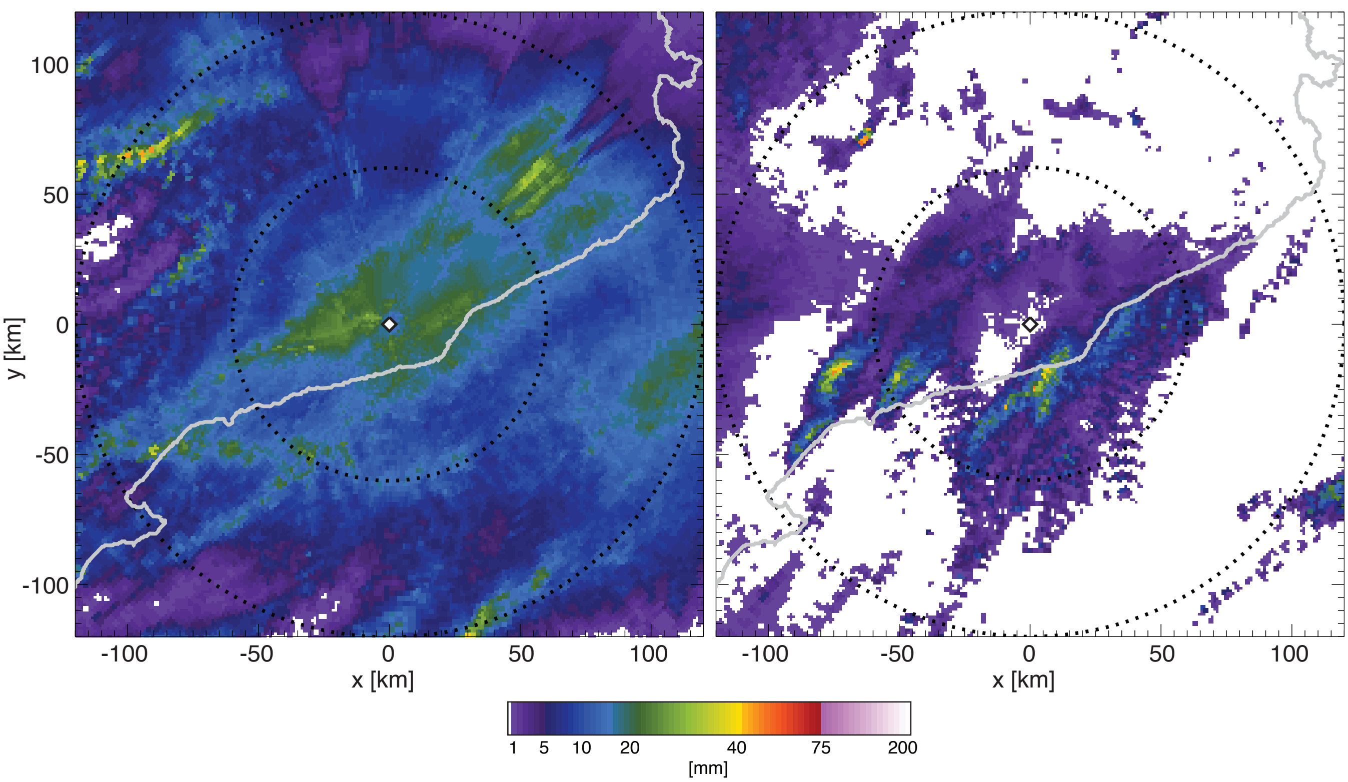

Fig. 3. Estimated rainfall accumulations for the two rainfall events analyzed here: 19 July 2001 (left), and 08 October 2002(right).

Here, we present the results for two significantly different events: (a) on 19 July 2001 a widespread rainfall situation affected the radar domain for about 12 hours; (b) in the evening of 08 October 2002, small scale convective cells affected the southern part of the domain and organized into a mesoscale convective system until the end of the day (Fig. 2 shows the reflectivity fields for 2 time steps during these events, and the event accumulations from reflectivity measurements are presented in Figure 3).

Table 1 shows the scores resulting from comparing the accumulated rainfall estimates computed from the reflectivity fields reconstructed using the different tested methods. For the event of 19 July 2001 the best scores are obtained with the methods that include horizontal interpolation (similar score values are obtained with the methods HOR, HV, HT and SD2001). This could be expected, given the widespread nature of the case. Consequently, the scatter plots between rainfall accumulations obtained from reference and reconstructed reflectivity with these methods show a very good agreement (as can be seen in Fig. 4 for the HV method). On the other hand, the reconstruction with the VERT methods shows the effect of the more variability in the vertical due to the contamination by the bright band and the underestimation of rainfall reflectivities when the observations are taken aloft in the snow layers (see right panel of Fig. 4).

Table 1. Results obtained with the different tested methodologies for the two analyzed events. “MAE”, “MRAE” and “corr” stand for “mean absolute error”, “mean relative absolute error” and “correlation”, respectively. The grey shaded cells indicate the method that obtained the best results for each score.

	19 July 2001				08 October 2002			
	Bias [mm]	MAE [mm]	MRAE [%]	corr	Bias [mm]	MAE [mm]	MRAE [%]	corr
HOR	0.00	0.89	20.7	0.96	0.19	0.90	125.5	0.79
VERT	-2.05	2.96	42.0	0.77	-0.22	0.59	52.7	0.91
TIM	0.17	1.62	31.9	0.90	-0.21	1.06	74.4	0.61
HV	-0.17	0.87	18.7	0.96	0.02	0.56	63.9	0.90
HT	0.00	0.94	21.3	0.96	0.19	0.90	125.5	0.79
SD2001	-0.08	0.86	20.2	0.96	-0.05	0.71	65.0	0.84

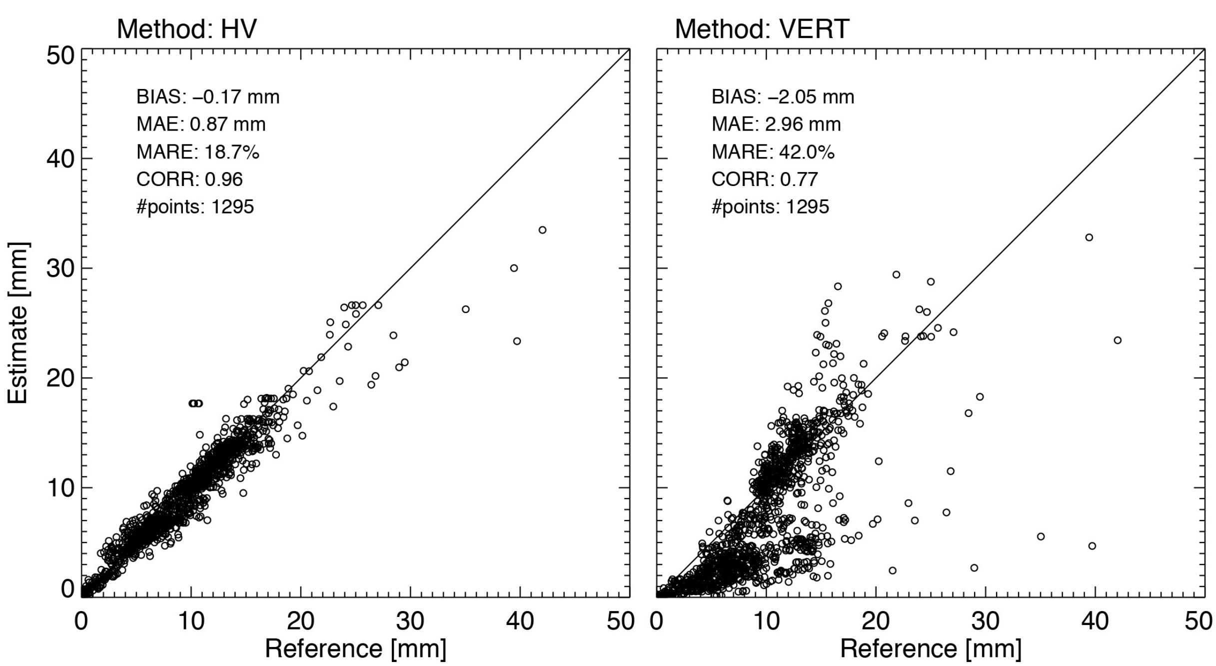

Fig. 4. Scatter plot between the rainfall accumulations estimated from reference and reconstructed reflectivity fields using the HV and VERT methods (left and right, respectively) and corresponding to the event of 19 July 2001.

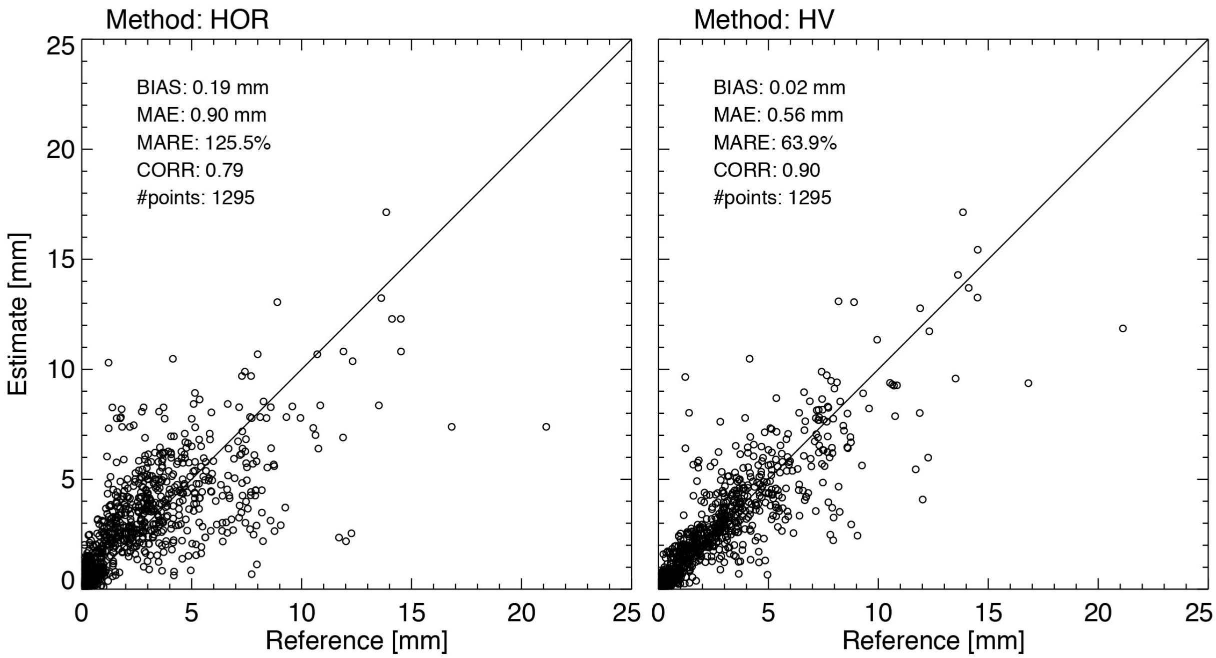

Fig. 5. Same as Fig. 4, but for the event of 08 October 2002 and for the HOR and HV methods.

Contrarily, the methods that include vertical extrapolation (VERT, HV and SD2001) show the best performance for the case of 08 October 2002 due to the high variability of the field in the horizontal. Similarly as for the event of 19 July 2001, both HV and SD2001 seem to adapt to the rainfall situation rather well, with HV obtaining slightly better results.

Finally the methods that use information from the previous times steps (HT and TIM) showed an intermediate performance for both cases, and past information did not seem to have a major contribution to the reconstruction.

5. CONCLUSION

This work analyzes different approaches to reconstruct the radar signal in areas contaminated by ground clutter. The proposed framework adapts to the meteorological situation through the information of the spatio-temporal variability of the field provided by the multi-dimensional semi-variogram.

The results for the analyzed event suggest that the contribution of time is not fundamental, and the HV method is the one that adapted the best to the two analyzed events.

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